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# CLIMATOLOGY OF STAGNATING ANTICYCLONES EAST OF THE ROCKY MOUNTAINS 1936-1965

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# CLIMATOLOGY OF STAGNATING ANTICYCLONES EAST OF THE ROCKY MOUNTAINS, 1936 - 1965

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## ABSTRACT

Since stagnating anticyclones are often associated with incidents of heavy air pollution in urban areas, a 30-year climatology is presented to delineate occurrences of stagnating anticyclones in the eastern United States. Occurrences of stagnation are determined on the basis of pressure-gradient values considered with other meteorological factors. Affected areas are depicted on maps by use of a system of grid points. Data showing cases of stagnation (i.e., episodes) and total days of stagnation indicate that stagnation is most likely to occur in autumn months.

# CLIMATOLOGY OF STAGNATING ANTICYCLONES EAST OF THE ROCKY MOUNTAINS, 1936-1965

## INTRODUCTION

This study combines the results of two separate investigations by the author. The first study *(1)* covers a period of 21 years (1936-1946); the second, a period of 9 years (1957-1965). The combined results of these studies are consolidated in a 30-year synoptic climatology of stagnating high-pressure systems in the eastern part of the United States.

Our chief interest in these stagnating anticyclones is their association with incidents of heavy air pollution in urban areas. Such anticyclones usually linger over an area for a protracted period (4 days or more). During this period surface wind speeds may be very low, and circulation at the surface is therefore insufficient to diffuse the accumulated pollutants of the local atmosphere. The resulting accumulations cause distressful and possibly hazardous conditions for inhabitants of the area.

In recent years, because of a rapid increase in urban living, the air pollution problem has become more and more aggravating and has commanded considerable attention. Our population is growing, and heavy industries are concentrated in relatively congested areas. Thus the possibilities that polluted air can affect human life adversely are also increasing. Since the major air pollution episodes are usually associated with stagnating anticyclones in or near urban areas, the synoptic climatology presented in this report may be useful in efforts now under way to prevent harmful effects of air pollution upon human life in the future.

## PRESSURE GRADIENT

There are few studies of air pollution climatology on record. After considerable preliminary experimentation, it was decided to employ a technique based on pressure gradient for determining the occurrence of cases of stagnation. This procedure is desirable because the pressure gradient gives a more representative picture of the general flow near the surface of the earth than do individual surface wind measurements. Willett evaluated the significant surface wind during the extreme smog development at Donora, Pennsylvania, in October 1948. At no time during a 4-day period was the maximum surface wind greater than 8 mph *(2)*. In this study, therefore, the limiting wind speed taken at anemometer level is assumed to be 7.5 knots. The authors of Dynamic Meteorology and Weather Forecasting show (in Table 12.35.1) the ratio between surface wind and geostrophic wind speed.

At 30°N latitude over land, this ratio is 0.31 and at 40°N latitude the value is 0.38 *(3)*. Willett maintains that the surface winds are observed to average about 2/5 of the gradient wind speed *(4)*. Brunt states that the value for surface wind speed should be about 0.7 times the geostrophic value for light winds *(5)*. In this study, the value of 0.5 has been adopted as the ratio between surface wind speed and geostrophic wind speed. Usually the difference between the geostrophic and the gradient wind speeds is small, and for this reason these two terms are used interchangeably by many authorities. As added confirmation for the 15-knot geostrophic value, J. J. George found that the average maximum gradient (geostrophic) wind speed that allows the formation of fog is close to 15.0 mph *(6)*.

## METHOD AND PROCEDURES

All the apparent stagnant anticyclones that have occurred between 1936 and 1965 east of the Rocky Mountains were selected for this study. The following procedures were used in determining cases of stagnation with the pressure gradient method:

**Step 1.** The United States Weather Bureau Daily Map *(7)* containing synoptic sea-level analysis was used exclusively to determine the pressure gradient. Before 1936, available upper-air information was sparse and inconclusive. The period of this survey extends for 30 years, 1936-1965.

All anticyclones that showed a possibility of stagnation for 4 days or more were recorded. These cases were carefully checked to determine whether portions of areas of stagnation as defined below overlapped for periods of 4 days or more. In Figure 1, the technique for determining stagnant areas is shown. For simplicity in this figure, the effect of latitude on the geostrophic wind is not considered, and therefore the geostrophic wind is constant for a given pressure gradient. In the numerical evaluations latitude was considered, and the pressure gradient corresponding to a 15-knot geostrophic wind was determined at each 5 degrees of latitude from 27.5 to 47.5. In the isobaric channel ST of Figure 1, the geostrophic wind changes from more than 15 knots to less than 15 knots at points C and D, with the stronger winds to the northeast. In the isobaric channel RS, the geostrophic wind speed is everywhere more than 15 knots. Therefore, the dashed curve delineating area of stagnation, as defined above, is drawn coincident with the isobar approximately up to the points C and D. Within the isobar T the geostrophic wind is everywhere less than 15 knots. Therefore, the dashed curve delineates the area of stagnation as drawn coincident with the isobar T approximately up to the points C and D. The dashed line is "faired-in" across the isobaric channel at points C and D. The region enclosed by the dashed line represents the area of stagnation.

**Step 2.** A map of the United States from the Rocky Mountains to the east coast was divided into a set of grid points at every 2 degrees of latitude and of longitude (Figure 2). An overlay pattern was then used to facilitate the locating of the grid points that lay within stagnant areas. The grid points of the "squares" thus located were then numbered. The daily records of areas of stagnation were recorded by means of these points on a worksheet. It was then possible to read off areas of stagnation for 4, 5, 6, and 7 or more consecutive days.

**Step 3.** Wherever frontal areas overlapped areas of apparent stagnation, the latter were excluded because of changing air masses, cloudiness, wind speed, and other elements.

**Step 4.** Areas of precipitation were excluded because of the cleansing properties of precipitation.

**Step 5.** It was discovered that only warm highs meet the criteria for stagnation conditions, since cold highs do not persist long enough. Warm anticyclones are deep, stagnant systems; the high pressure prevails far up into the troposphere and may extend into the stratosphere. Each case was checked for either a trough or a ridge in the area of interest at approximately 10,000 feet.

## SUMMARY OF RESULTS

The 30-year study yields results so similar to those of the earlier survey that most of the summary remarks are confined to the latter.

Table I is a chronological presentation of all cases of stagnation. Because of the strict criteria, some cases may be ignored that might have resulted in potentially serious pollution situations.

In Figure 3, the upper values (above each grid point) are the total number of stagnation cases (4 or more days) and the lower values are the total number of days of stagnation. Dashed isopleths show the distribution of the number of stagnation cases; solid isopleths, the distribution of the number of days of stagnation. They are distributed similarly. This chart suggests a strong influence of the Bermuda High on the east coast. A maximum frequency in both the number of cases and the number of days stagnation occurs in an area that covers parts of Georgia, South Carolina, and North Carolina. This region is frequently dominated by the western extension of this semipermanent high-pressure area.

Figure 4 shows the geographical distribution of annual occurrences of cases of stagnation for 7 or more days. The values given are the total for the entire 30-year period, 1936-1965. These can be compared with Figure 3, the total annual number of stagnation cases for 4 or more days (dashed isopleths).

A monthly distribution of the number of cases of stagnation for 4, 5, 6, or 7 or more days and of the total number of days of stagnation is given in Table II.

Figure 5 depicts the distribution by months of the number of cases of stagnation for 4, 5, 6, and 7 or more days. This figure illustrates Table II graphically. The primary peak for 4 or more days occurred in October; a secondary maximum occurred in May. Figure 5 also shows the percentage distribution by months of cases of stagnation for 4 or more days; Table III presents these data in numerical form.

Geographical distribution by months of the occurrences of stagnation episodes of 4 or more days is given in Figure 6. Each month was analyzed, and isopleths were drawn for equal numbers of cases. The 4 months with the maximum frequency of cases at any one grid point are May, September, October,

and November. In May, 14 cases of stagnation occurred over South Carolina. In the last 9 years during this month the maximum number of cases shifted to northern Florida. In September, the maximum number of cases, 16, occurred in Pennsylvania, near 40°N and 75°W; the secondary maximum, 11 cases, occurred over eastern Tennessee. The two peak areas tend to combine. In October, 21 cases of stagnation occurred over northern Georgia; in November, 12 cases occurred in central South Carolina. Wexler *(8)* also finds October the month most favorable for the occurrence of deep anticyclones and hazardous smog episodes. Klein *(9)* depicts the number of different highs for 5-degree squares for each month during 20 selected years of the original Historical Map Series, 1904-1914 and 1924-1937. In Klein's paper, charts 21, 22, and 23 for September, October, and November are somewhat similar to those for the same months shown in Figure 6, but with centers of maximum frequency displaced somewhat northward. He also gives the number of days with highs (both migratory and stationary) during the 40 years from 1899-1939. September and October apparently are crucial months when stagnation is most likely to occur.

Data for additional years have not affected the original location and distribution of stagnation anticyclones in the eastern United States. Thus, these data appear to furnish a reliable climatology of such events.

## ACKNOWLEDGMENTS

Dr. Lester Machta initiated the project, established the criteria for classifying the stagnating wind speeds, and suggested the procedures to be followed in analyzing the weather charts. The author is also grateful to Donald H. Pack, Dr. James K. Angell, and Fred D. White for their many suggestions and constructive criticism. The diagrams were drafted by Marguerite M. Hodges; Roland V. Goulait assisted in tabulating the data.

## Table I. Stagnation Cases in the United States, East of the Rocky Mountains, 1936-1965.

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1936 | | 23-26 | | | 6-11<br>23-27 | | | | | | | 21-27 | 4 |
| 1937 | | | | 17-20 | | | | 14-17 | 21-25<br>S27-01 | | 23-26 | | 5 |
| 1938 | | | | 12-17 | 17-21 | | | 9-12<br>15-17<br>19-24 | | 8-13<br>18-20<br>25-28 | | | 8 |
| 1939 | | | | | 4-7 | 24-28 | | | 23-26 | 4-10 | 13-18 | | 5 |
| 1940 | | | | 1-5 | 5-9 | 2-6 | | | 3-7<br>17-21 | 10-15<br>23-28 | 18-21 | | 8 |
| 1941 | | | | 8-12<br>14-20<br>A21-M1 | 19-22 | 18-22 | | | 19-22<br>S28-01 | 12-16 | | | 8 |
| 1942 | 11-14 | | | 14-17<br>23-26 | A29-M3 | M30-J3 | 18-21 | | 8-11<br>12-15 | 7-10 | | | 9 |
| 1943 | | 17-21 | | 25-29 | | M30-J5<br>9-16 | | 3-7<br>19-26<br>A29-S2 | 26-29 | 3-11<br>18-21 | 18-21 | | 11 |
| 1944 | | 23-28 | | | A30-M5<br>12-18 | M30-J3 | 4-7 | | | 16-19 | | 4-7 | 7 |
| 1945 | | | 16-20<br>M28-A1 | | | 10-13 | | A27-S1 | | 027-N3 | | | 5 |
| 1946 | | | | | | 22-27 | 27-30 | | 3-7<br>13-20<br>26-29 | 2-7<br>14-18<br>20-25 | 11-14 | 3-11 | 10 |
| 1947 | | | | | | 20-25 | | 11-18 | | 1-8 | | 1-5 | 4 |
| 1948 | | | | | | 1-4 | 2-6<br>9-12 | 21-30 | 1-8 | 24-31 | | | 6 |
| 1949 | | | | | 13-16 | | 23-20 | | | 9-12<br>19-22 | 6-9 | | 5 |
| 1950 | | | | | | 6-9<br>13-20 | | 7-12<br>22-27 | S26-03 | 16-19<br>029-N3 | 6-9 | | 8 |
| 1951 | 27-30 | | 2-5 | | 14-18 | | | | | | 20-25<br>N28-D3 | | 5 |
| 1952 | D31-J5*<br>12-18 | | | 18-24 | | 23-28 | | 23-28 | 9-14<br>S27-01 | 22-27<br>030-N2 | | | 9 |
| 1953 | 13-16 | | | | | | 10-14 | A17-S2 | | | 030-N3<br>13-20 | | 5 |
| 1954 | | | | | | | J26-A1 | | 1-7 | 1-6<br>20-27 | | | 4 |
| 1955 | | | F28-M3<br>12-19 | | | M31-J6<br>15-18 | 1-5 | 1-6<br>27-30 | | 9-13 | 12-17 | | 9 |
| 1956 | | | | 3-6 | 10-15 | 13-19<br>23-27 | | | 11-14<br>26-29 | 11-16 | | | 7 |
| 1957 | J26-F1 | | 23-26 | 22-28 | 7-10<br>M29-J1 | 13-17 | 11-14<br>16-20 | 6-9 | | 6-10<br>11-16 | | 13-19 | 12 |
| 1958 | | | | 17-20 | 14-17 | J28-J4 | | | 12-16<br>23-26 | 12-17 | 11-14 | | 7 |
| 1959 | 11-15<br>23-27 | | | 5-10<br>14-18<br>24-29 | 1-5<br>27-30 | 8-12 | | 11-16<br>20-23 | 4-10<br>19-26 | 3-7 | 8-11 | 8-11<br>14-17 | 16 |
| 1960 | 9-12 | | | 11-17<br>23-26 | 3-7<br>14-21 | 8-13<br>25-30 | | 17-20 | 6-9<br>22-25 | 8-14 | 12-16<br>18-23<br>25-28 | 2-7<br>17-20 | 16 |
| 1961 | | 13-17 | | 22-27 | | 2-8 | | | 9-13<br>21-24 | 6-13 | | | 6 |
| 1962 | | | | | 16-20 | | | 23-26<br>A29-S2 | | 11-14 | N27-D4 | | 5 |
| 1963 | | | | M30-A4<br>17-22 | 8-11 | | | 3-6 | 7-11<br>16-20<br>24-27 | 1-4<br>14-20<br>23-26 | 16-19 | | 11 |
| 1964 | | | | 17-23 | 7-10<br>16-20 | | | | 1-4 | 11-15<br>24-27 | | | 6 |
| 1965 | | | | | 1-8<br>15-20 | | | | 4-9<br>19-23 | 25-29 | | D30-J2** | 6 |
| TOTAL | 9 | 4 | 6 | 22 | 25 | 24 | 11 | 23 | 34 | 40 | 19 | 10 | 227 |

* Dec 31 - Jan 5 ** Dec 30 - Jan 2

Table II. Number of Stagnation Cases for Indicated Period and the Total Number of Days by Month, in the United States, East of the Rocky Mountains, 1936-1965.

| Month | Days | | | | | | | | Total Days |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 17 | |
| Jan | 9 | 5 | 3 | 2 | | | | | 46 |
| Feb | 4 | 3 | 1 | | | | | | 20 |
| Mar | 6 | 3 | 1 | 1 | 1 | | | | 30 |
| Apr | 22 | 16 | 12 | 6 | 1 | | | | 123 |
| May | 25 | 16 | 7 | 3 | 1 | | | | 127 |
| Jun | 24 | 20 | 11 | 7 | 2 | | | | 136 |
| Jul | 11 | 6 | 2 | 2 | 1 | | | | 55 |
| Aug | 23 | 15 | 11 | 4 | 4 | 2 | 2 | 1 | 131 |
| Sep | 34 | 19 | 8 | 6 | 3 | | | | 172 |
| Oct | 40 | 27 | 20 | 9 | 6 | 1 | | | 223 |
| Nov | 19 | 9 | 6 | 2 | 2 | | | | 95 |
| Dec | 10 | 5 | 3 | 3 | 1 | 1 | | | 53 |
| Total | 227 | 144 | 85 | 45 | 22 | 4 | 2 | 1 | 1211 |

Table III. Percentage Distribution of Cases of Stagnation for 4 or More Days by Month in the United States, East of the Rocky Mountains.

1936-1965

| Month | Day | Percent |
|---|---|---|
| | 4 | |
| Jan | 9 | 4.0 |
| Feb | 4 | 1.8 |
| Mar | 6 | 2.6 |
| Apr | 22 | 9.7 |
| May | 25 | 11.0 |
| Jun | 24 | 10.6 |
| Jul | 11 | 4.8 |
| Aug | 23 | 10.1 |
| Sep | 34 | 15.0 |
| Oct | 40 | 17.6 |
| Nov | 19 | 8.4 |
| Dec | 10 | 4.4 |
| Total | 142 | 100.0 |

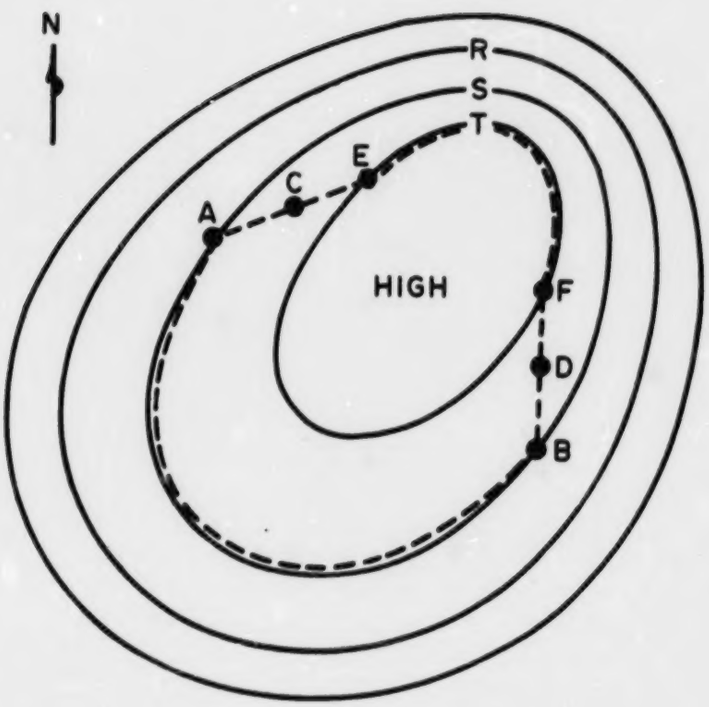


Figure 1. Schematic illustration of technique for determining stagnation areas.

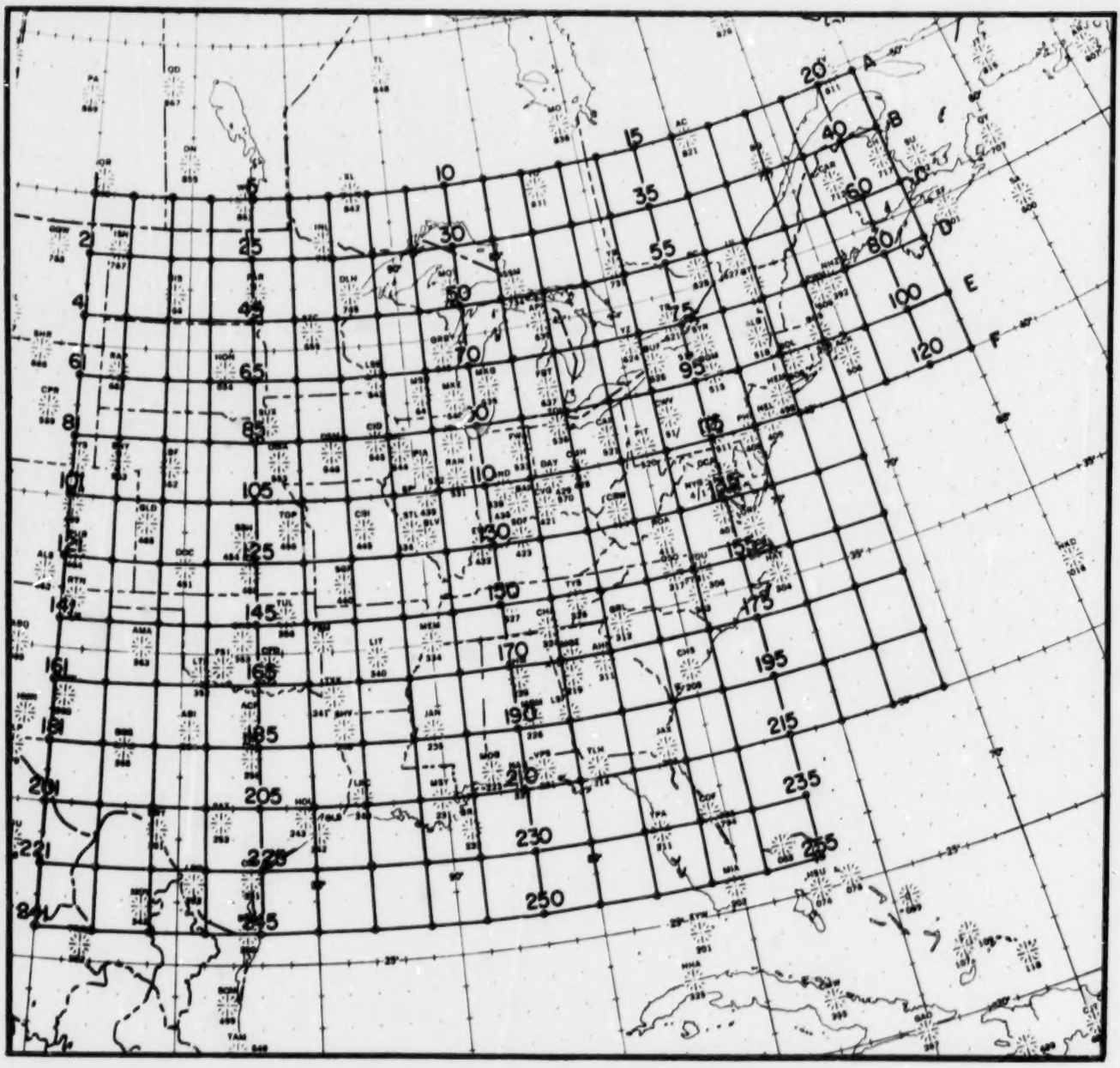


**Figure 2. Geographical data reduction grid.**

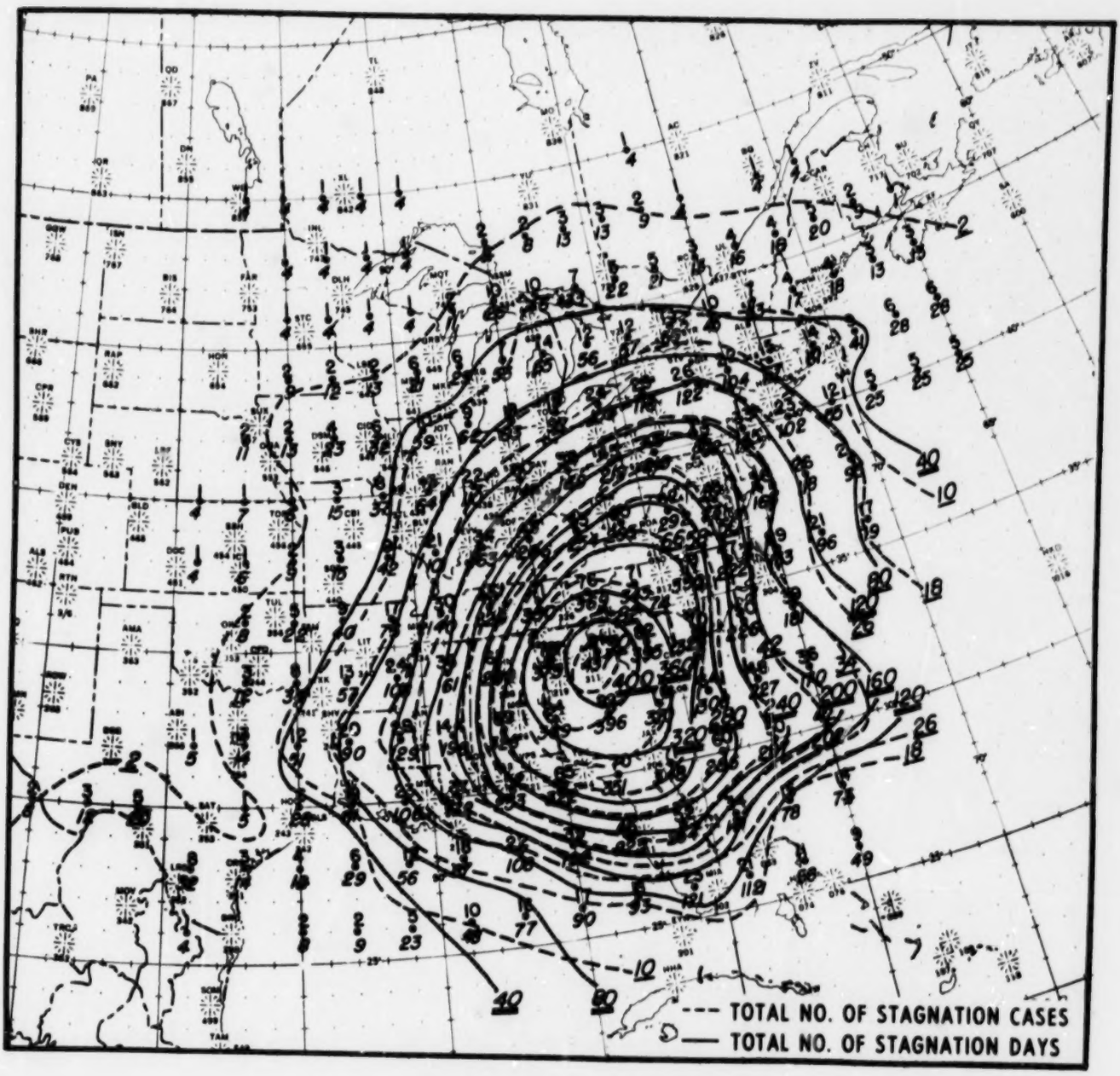


**Figure 3. Distribution of stagnation cases and stagnation days, 1936-1965.**

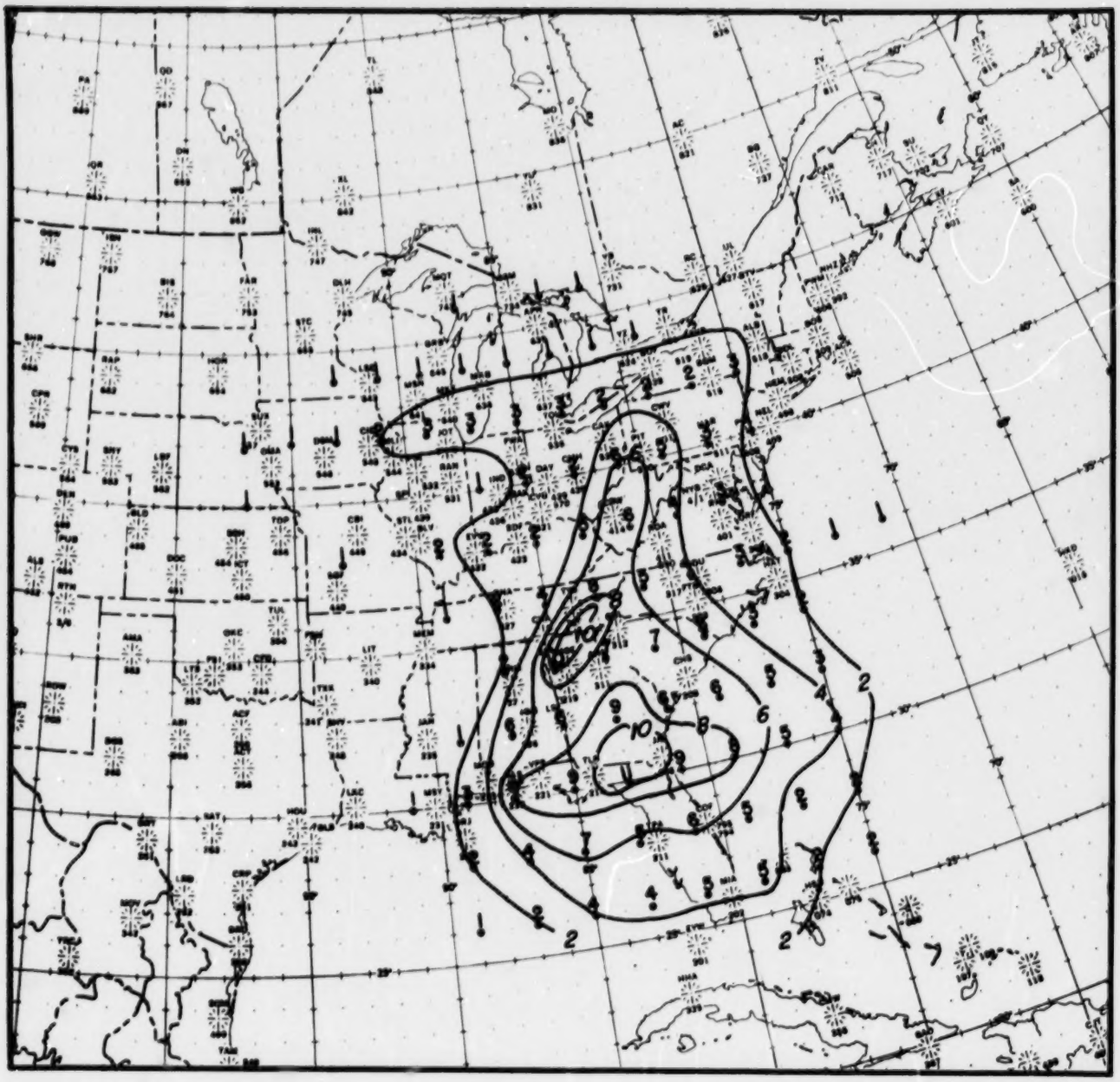


Figure 4. Total number of stagnation cases (7 or more days), 1936-1965.

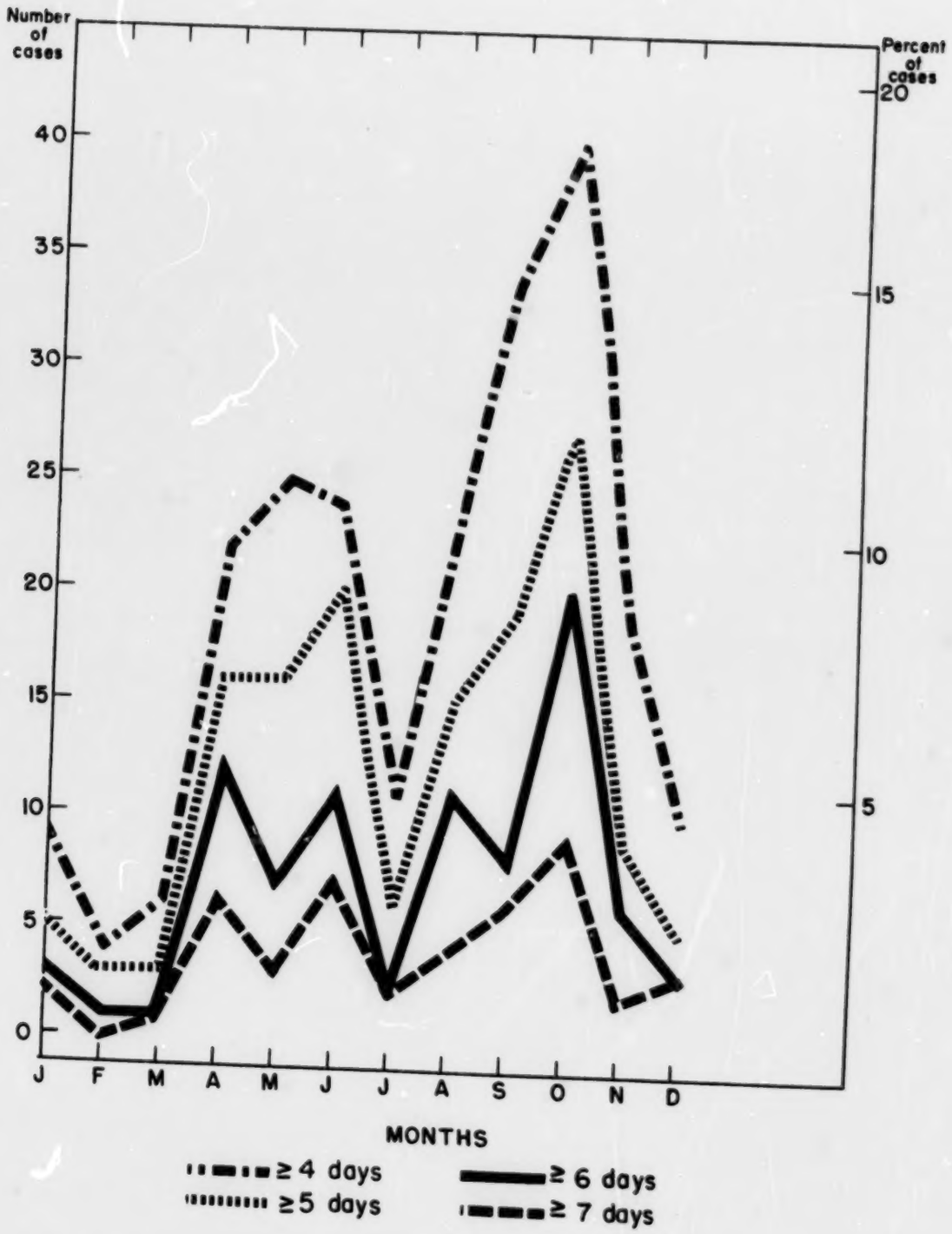


Figure 5. Number of stagnation cases for 4, 5, 6, and 7 or more days by month in the United States east of the Rocky Mountains, 1936-1965.

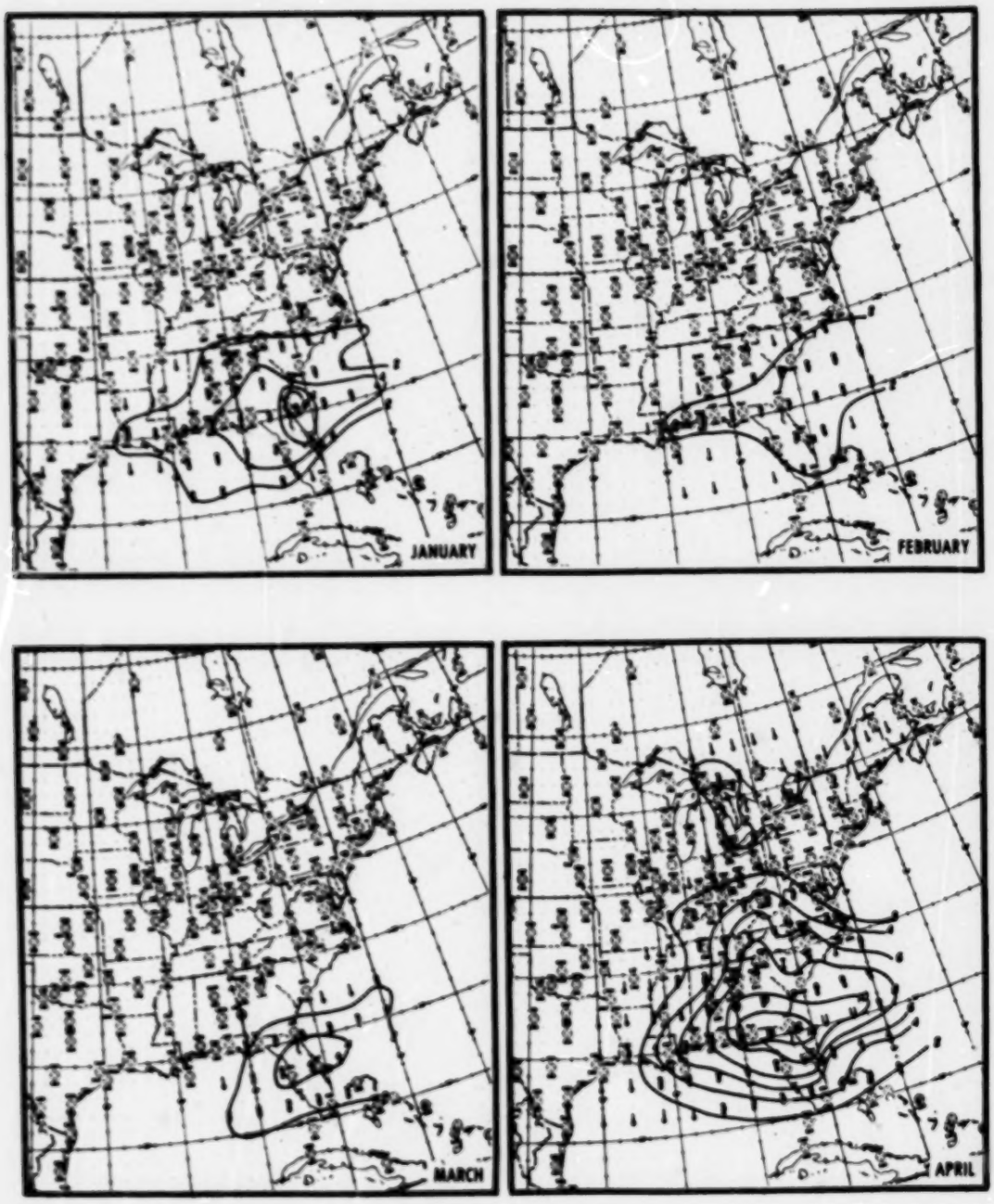


**Figure 6. Monthly distribution of number of cases of atmospheric stagnation (4 days or more), 1936-1965.**

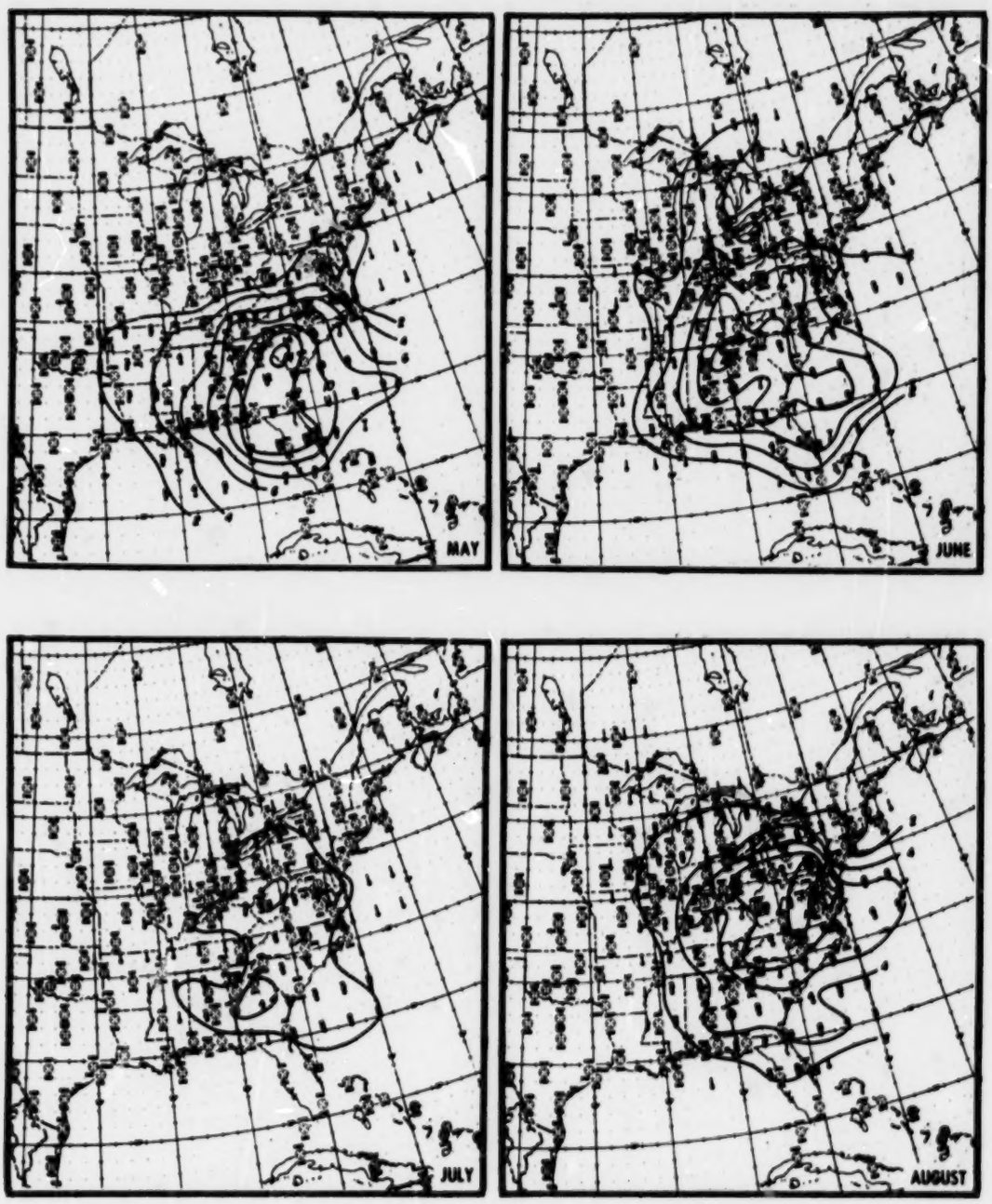


**Figure 6 (continued). Monthly distribution of number of cases of atmospheric stagnation (4 days or more), 1936-1965.**

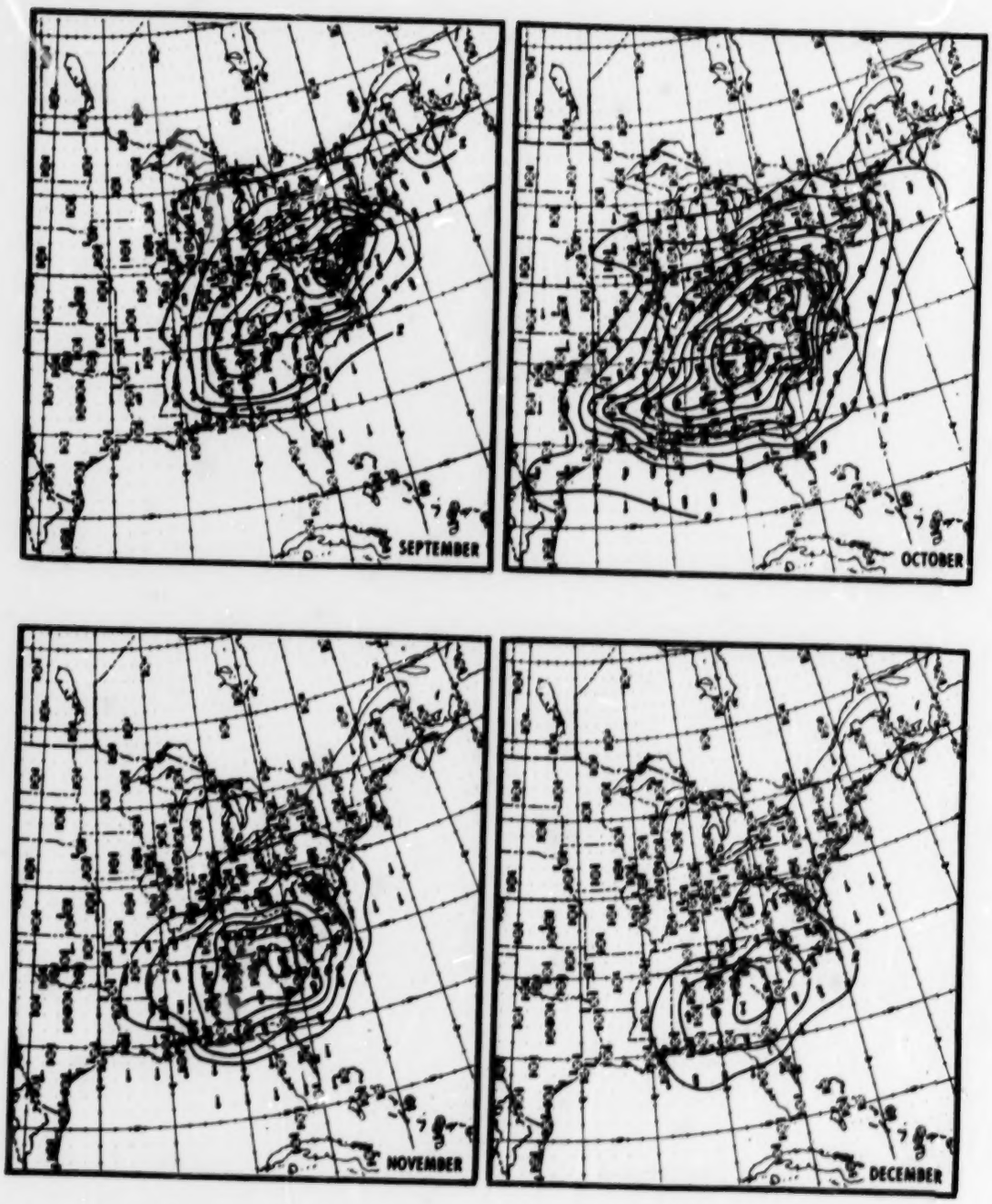


Figure 6 (continued). Monthly distribution of number of cases of atmospheric stagnation (4 days or more), 1936-1965.

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